roads have untreated faces of slopes after being cut, on which rock falls and minor slope collapses frequently occur. Some of the bridges are prone to dangers of scouring.

For the flood control and water quality, the catchment area management is important. Guatemala is a well-developed agricultural country that uses a large part of slopes as farmland. A slope with an inclination of 15 degrees or more tends to have significant washout of soil, causing debris flows and floods. The development on the mountainside of Agua volcano is considered to be one of the causes for the debris flow disaster that occurred in Ciudad Vieja in June 2002. Some major tasks to be completed remain such as assistance for tree planting in the upper reaches, restrictions on land use based on land use evaluation along rivers, setup of planned flood discharges, and planning for constructing revetments and embankments.

4.3.3 Hazard mapping

(1) Methods of hazard mapping

Two approaches to the estimation of hazardous areas are available, namely by evaluating the accumulation of events in which the past disasters occurred and by estimating the range of influence through a simulation based on certain conditions.

The empirical methods which allows to relatively rank the potential hazard of a point or area, may be adopted to establish land use plans. This approach has also the merit to avoid getting a wrong hazard estimation being itself concerned with cumulative hazard levels.

The simulation also allows estimating the hazardous areas with various disaster types, disaster scales, and occurrence locations by changing the disaster occurrence conditions. However, since the estimation conditions are specified, any disaster that occurs with different conditions may result with different results compared to the estimated ones.

Table 4.3-5 Approaches to estimation of hazardous areas in this project

Hazard Type	Major estimation item	Empirical Methods	Simulation-based evaluation
Seismic Hazards	Ground Motion		○
	liquefaction		○
Volcanic Hazards	Pyroclasitic Fall	○	○
	Pyroclasitic Flow		○
	Lave Flow		○
	Lahar		○
	Edifice Collapse	○	
Landslides	Landslide	○	
Floods	Inundation Area	○	○
	Inundation Depth		○

(2) Seismic hazards

There are five study areas: Guatemala City, Quetzaltenango, Mazatenango, Escuintla, and Puerto Barrios. The overall flow of seismic hazard estimation work is shown in Figure 4.3-6. The study items roughly consists of evaluation and classification of soil types, determination of target earthquakes, simulation of ground motion, and estimation of liquefaction potential. The following figure shows the outline of this study.

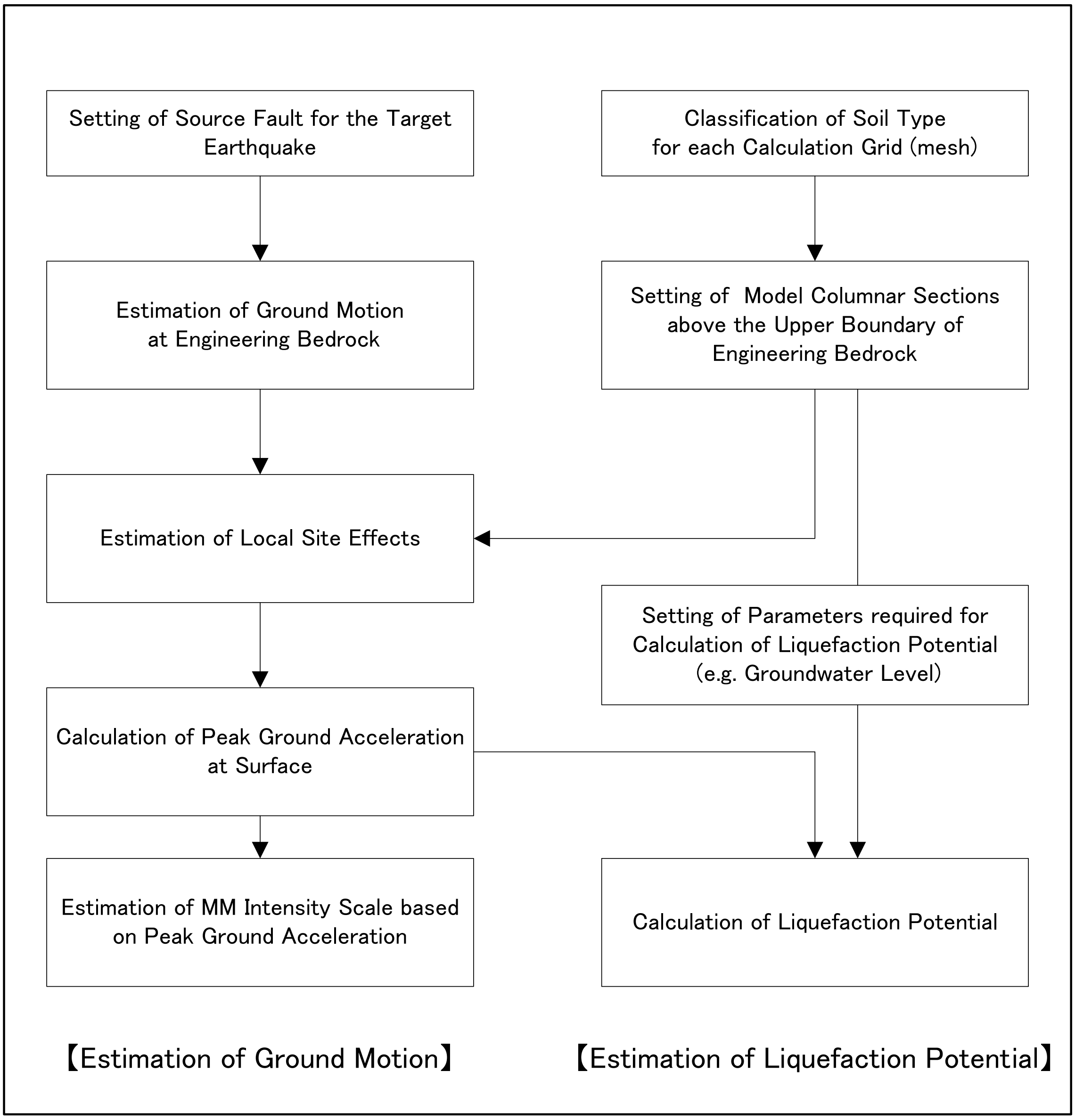

Figure 4.3-6 Flow of estimation of ground motion and liquefaction potential

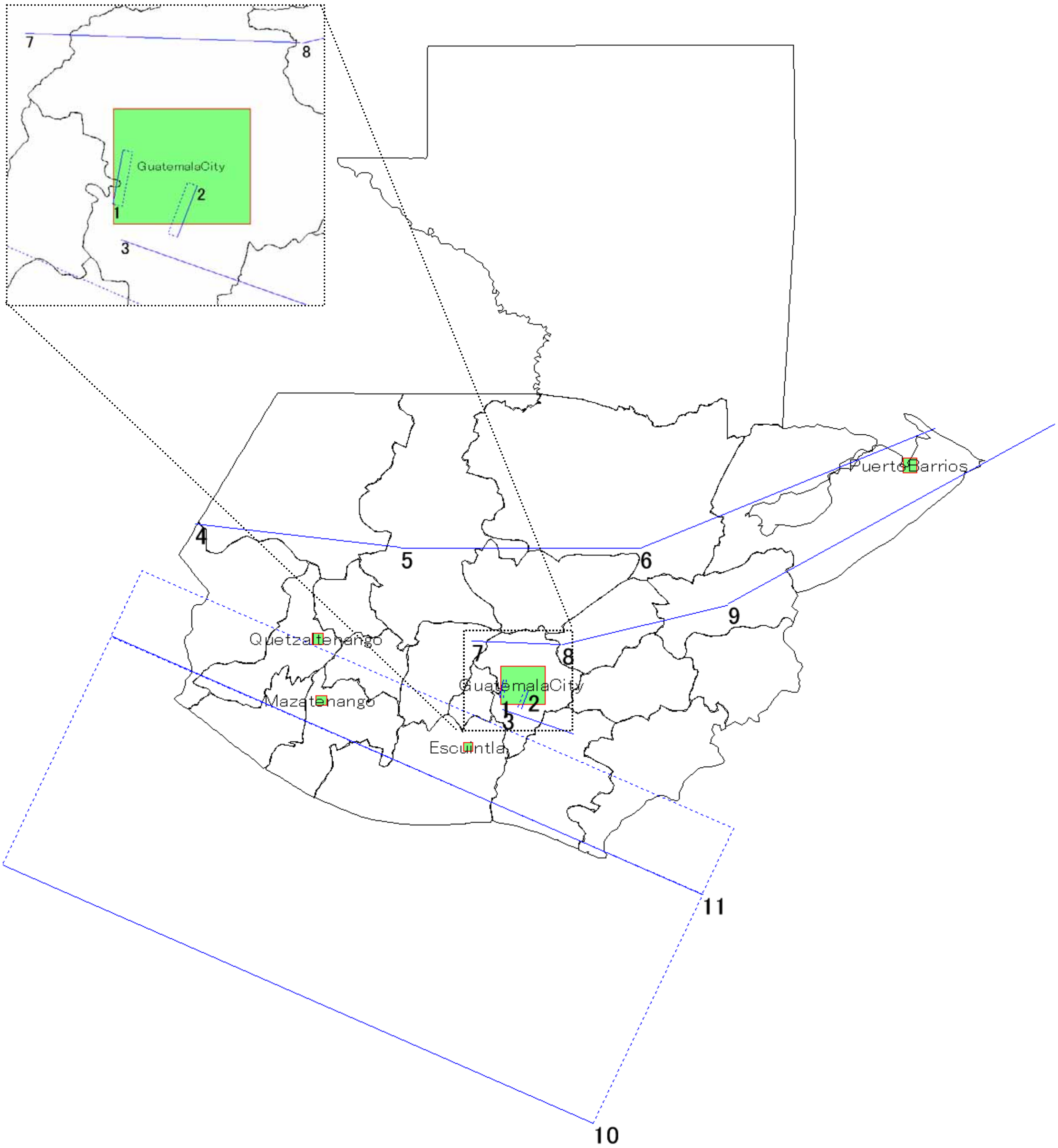

Figure 4.3-7 Distribution map of target earthquakes

(Numbers correspond to ones shown in **Table 4.3-6** The target earthquake of No.10 (or No.11) is assumed to have the source fault, of which size corresponds to moment magnitude 7.7, as a part of the shallow (or deep) segment of subduction zone, and to occur in the closest part to each study area on the segment.)

Table 4.3-6 List of assumed cases of ground motion and liquefaction potential

No	Target earthquake	Guatemala City	Quetzal-tenango	Maza-tenango	Escuintla	Puerto Barrios
1	Mixco	○				
2	Sta. Catarina Pinula	○				
3	Jalpatagua West Segment	○				
4	Chixoy-Polochic West Segment		○			
5	Chixoy-Polochic Central Segment	○				
6	Chixoy-Polochic East Segment					○
7	Motagua West Segment	○				
8	Motagua Central Segment	○				
9	Motagua East Segment					○
10	Subduction Shallow Segment	○	○	○	○	
11	Subduction Deep Segment	○	○	○	○	

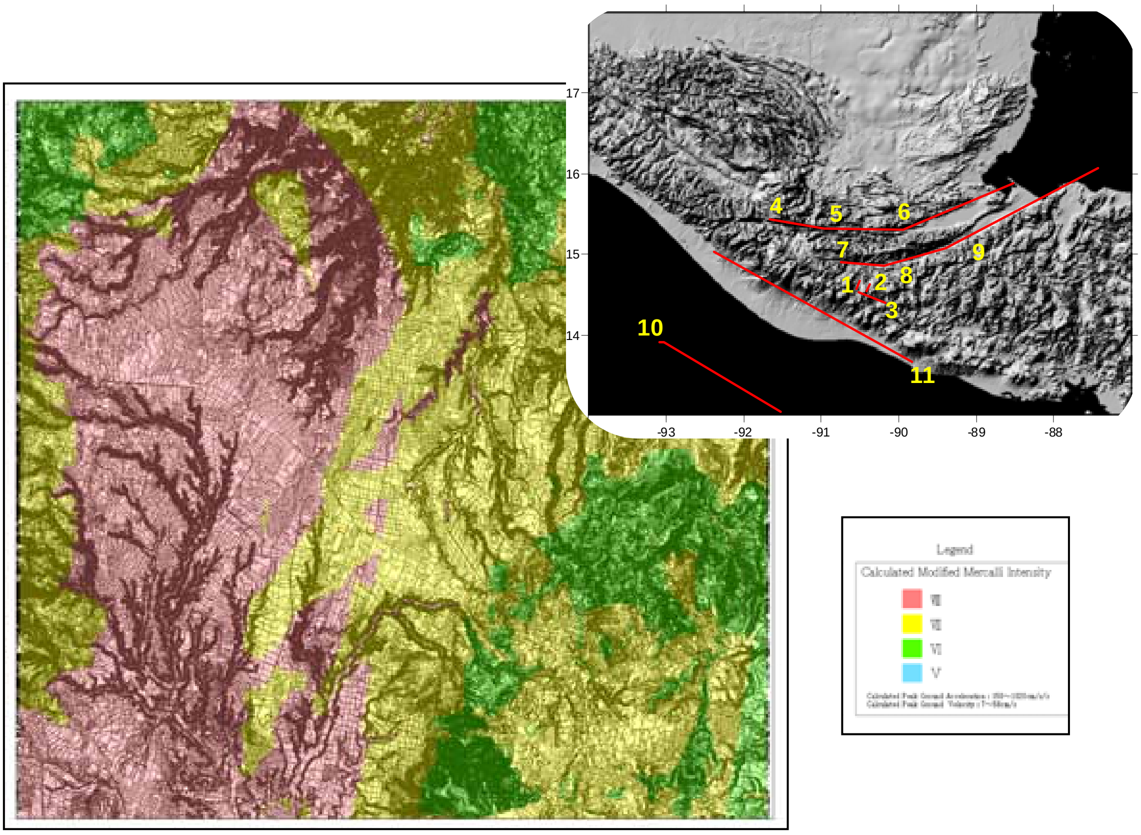

Figure 4.3-8 Seismic hazard map(Seismic intensity)

（In the case of the earthquake originated from Mixco fault in Guatemala city area）

(3) Volcanic Hazards

There are four volcanoes that were evaluated: Santiaguito, Cerro Quemado, Pacaya, and Tacaná. The overall flow of volcanic hazard evaluation process is shown in Figure 4.3-9.

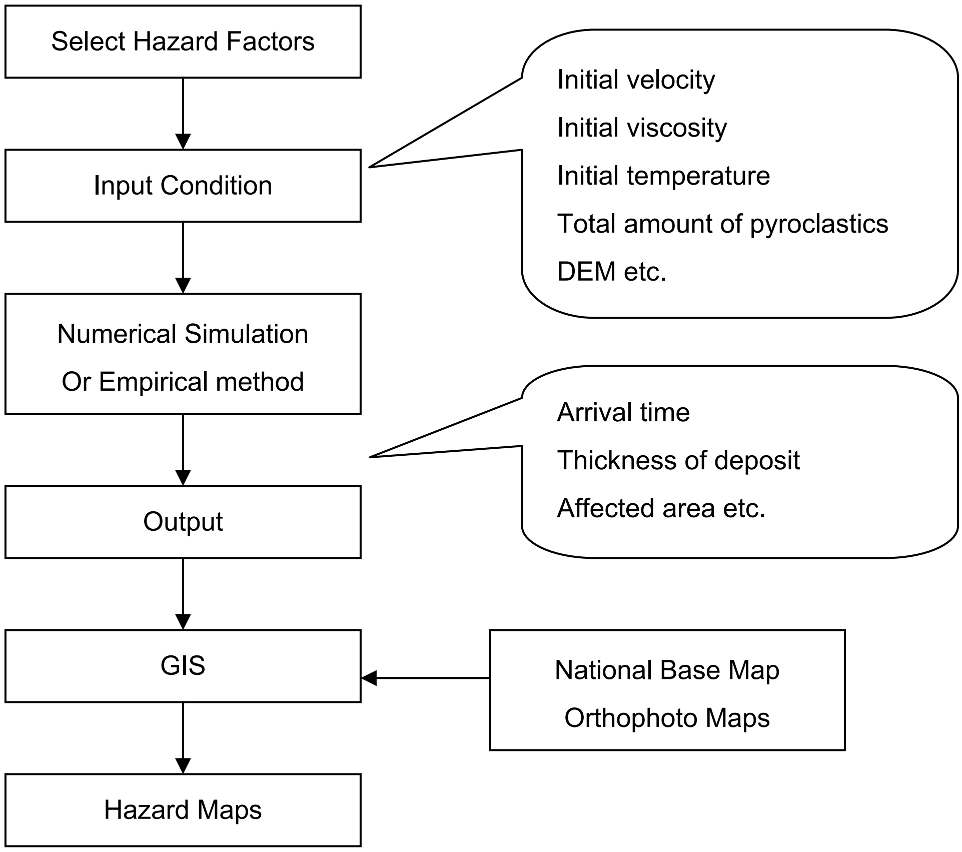

Figure 4.3-9 Flow of estimation of volcanic hazards

Table 4.3-7 Selection of hazard type

Volcanoes	Ash fall &Ejected Rocks	Pyroclastic flow	Lava flow	Lahar	Edifice collapse	Volcanic gas
Santiaguito	◎	◎	◎	◎	○	△
Cerro Quemado	◎	◎	◎	△	○	△
Pacaya	◎		◎	△	○	△
Tacaná	◎	○	◎	△	○	△

◎: Digital simulation ○: Simple digital simulation △: Empirical method

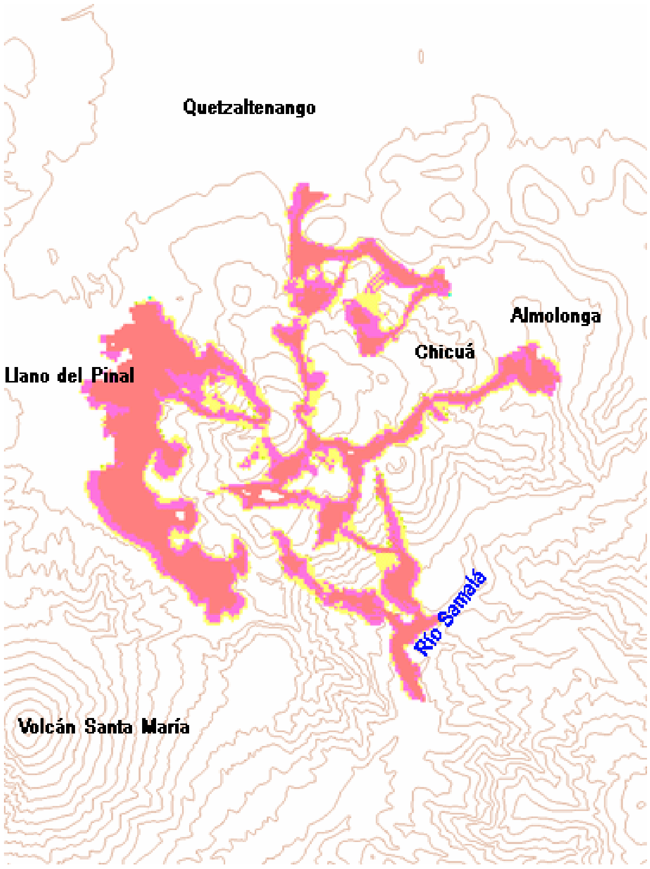

Figure 4.3-10 An example of volcanic hazard map
(Lava flow of Cerro Quemado volcano)

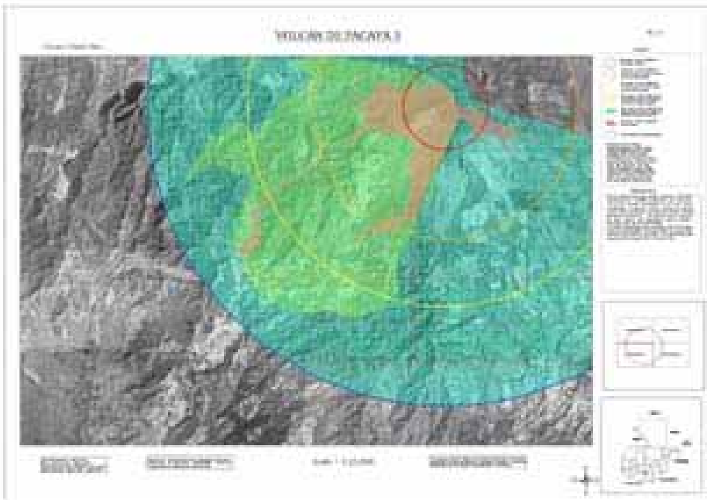

Figure 4.3-11 An example of volcanic hazard map
(Lava flow, edifice collapse and pyroclastic flow of Pacaya volcano)

(4) Landslide hazards

There are two study areas for landslides with different study methods and scales. The Detailed Study Areas include Guatemala City, Quetzaltenango, and Antigua, where landform classification and slope classification will be made to assess the landslide hazards. The two Wide Study Areas include the North-West Region and Central Region, where the slope classification and distribution of landslides, etc. will be studied.

The flow of these evaluation processes is shown in Figure 4.3-12.

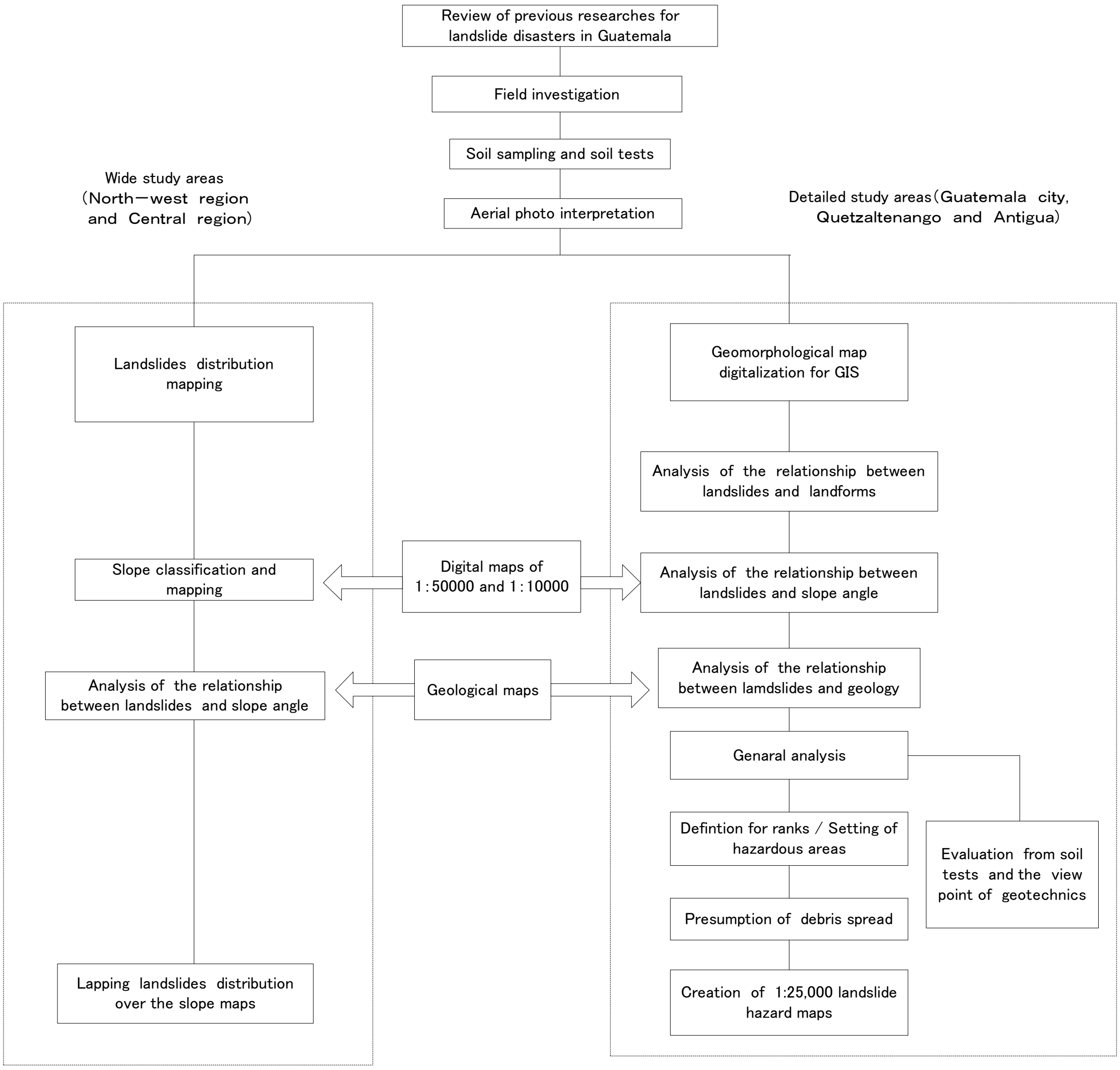

Figure 4.3-12 Flow of landslide hazard evaluation

Note: Landslides and slope collapses are handled as different items for analysis, for the landslide evaluation.

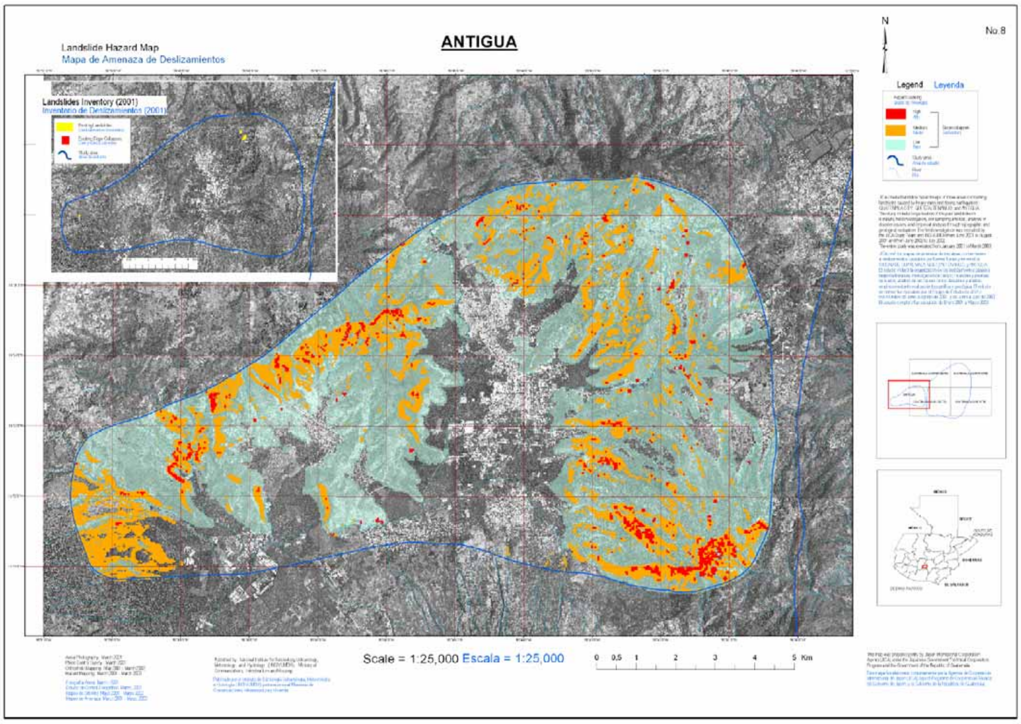

Figure 4.3-13 Sample landslide hazard map
(Detailed survey area: Antigua)

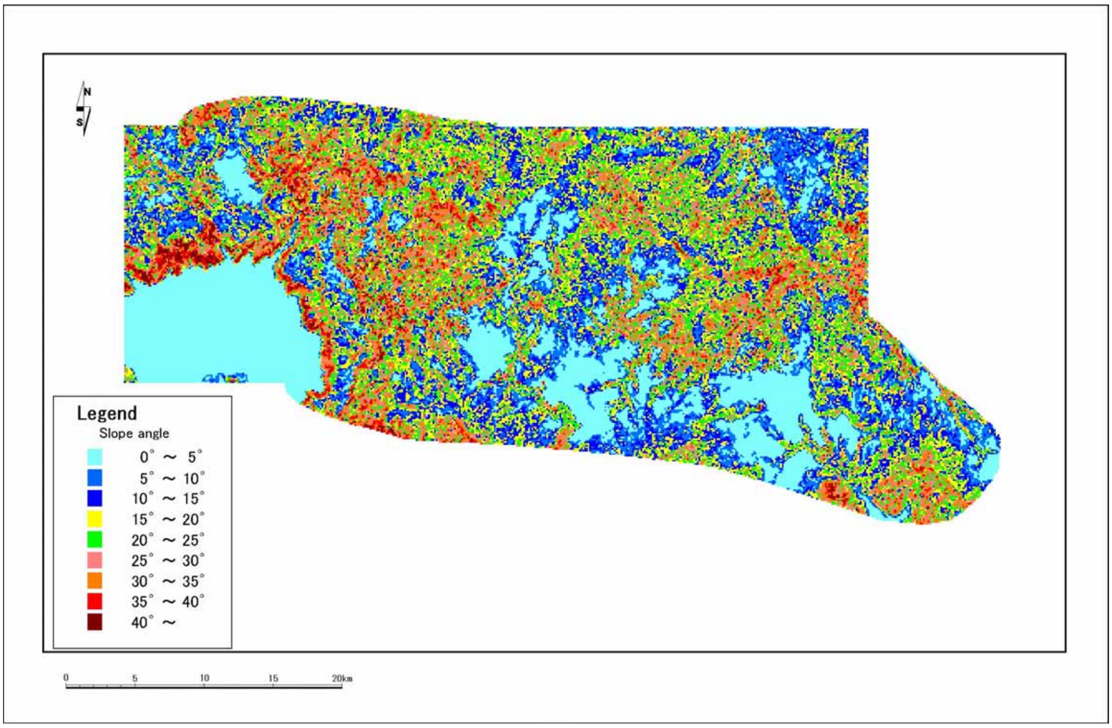

Figure 4.3-14 Sample landslide hazard map (Slope angle classification map)
(Detailed survey area: Central area)

(5) Floods

There are four rivers for which flood hazard maps were made: the María Linda, Achiguate, Acomé, and Samalá.

Flood hazard maps were created in the following method and workflow. For the Samalá River, a hazard map was created through flood simulation. For the remaining three rivers, hazard maps were created through landform classification and disaster history analysis

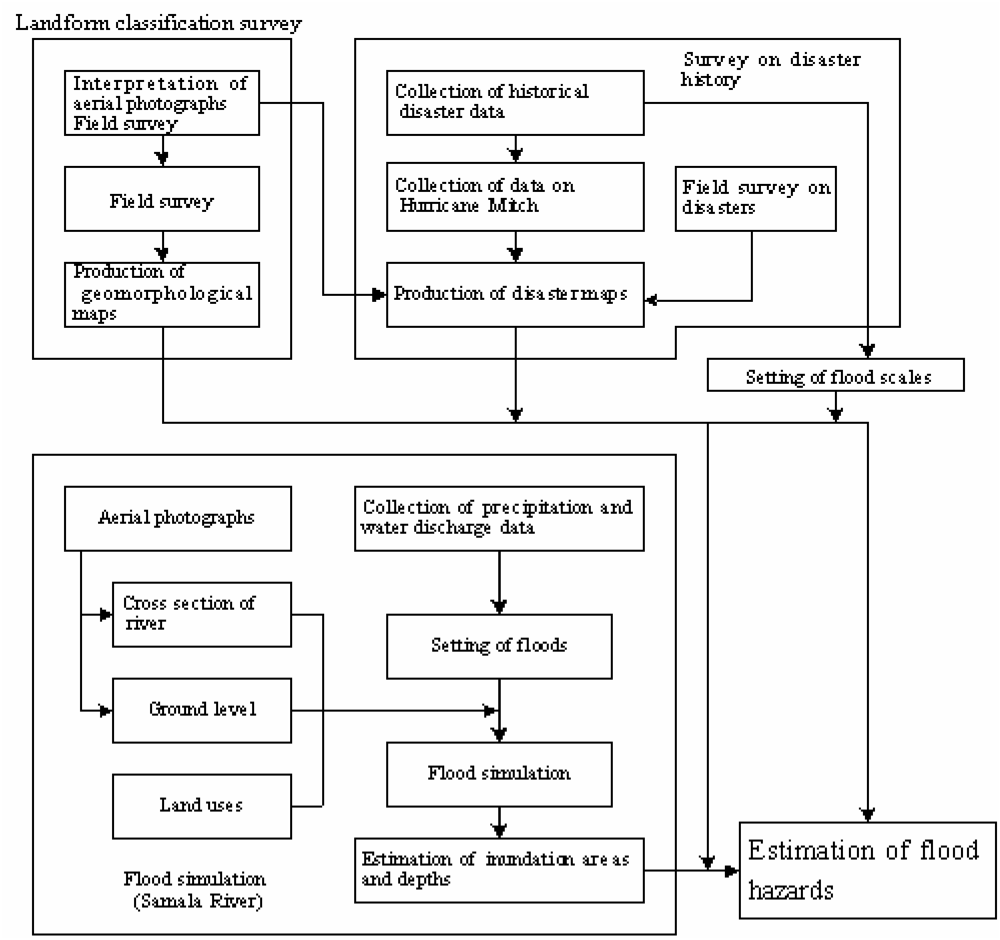

Figure 4.3-15 Flow of flood hazard map production

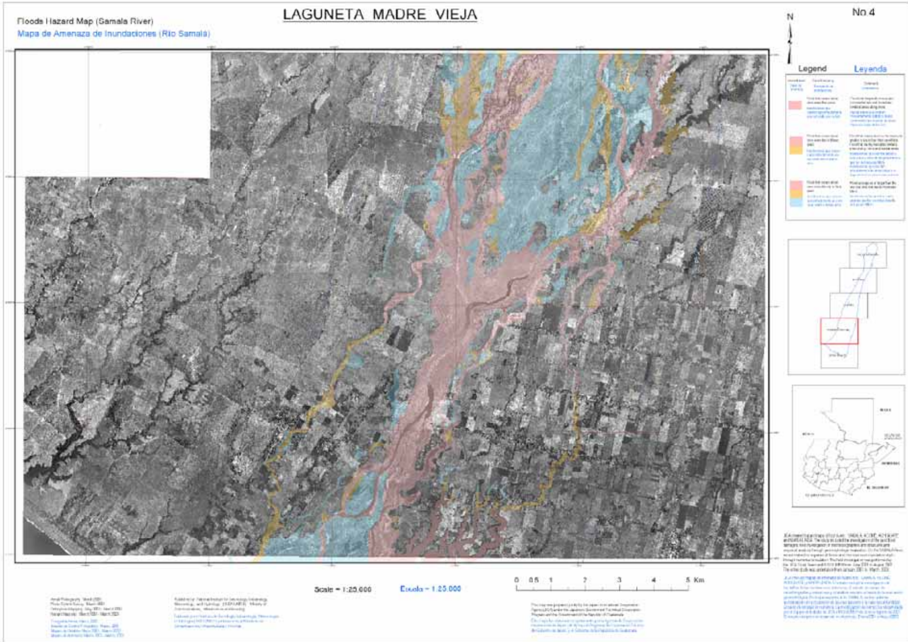

Figure 4.3-16 Example of flood hazard map
（simulation study area: Samala river）

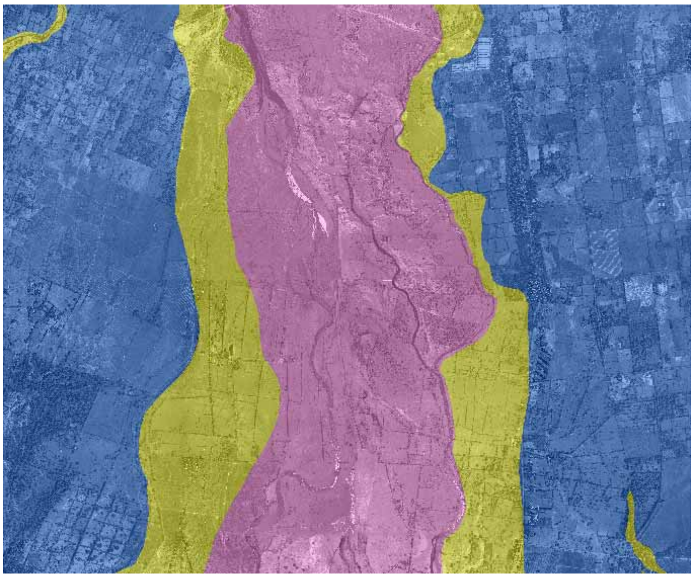

Figure 4.3-17 Example of flood hazard map
（by empirical method: Achiguate river）

(6) Hazard map GIS

JICA study team created various maps related to hazard maps in the Study. Furthermore, we collected several maps owned by the concerned organizations including INSIVUMEH. Whereas the maps were managed as paper-based ones previously, the computers and GIS software provided by JICA allow much of the map information to be managed now using GIS. We created Hazard Map GIS to organize the maps and allow INSIVUMEH to manage geographic information related to disaster information with ease. This system, intended to facilitate accumulation of disaster data in the future and management of hazard maps, will hopefully contribute to enhance the efficiency of operations of INSIVUMEH and, consequently, improve the disaster resistance of Guatemala. Furthermore, the engineers of INSIVUMEH participated in training of GIS as part of the Study Team's technology transfer training and could improve their technological skills for GIS. It is recommended that, in the future, INSIVUMEH manages various map data including the existing one on this system.

The following figure shows the structure of Hazard Map GIS in INSIVUMEH.

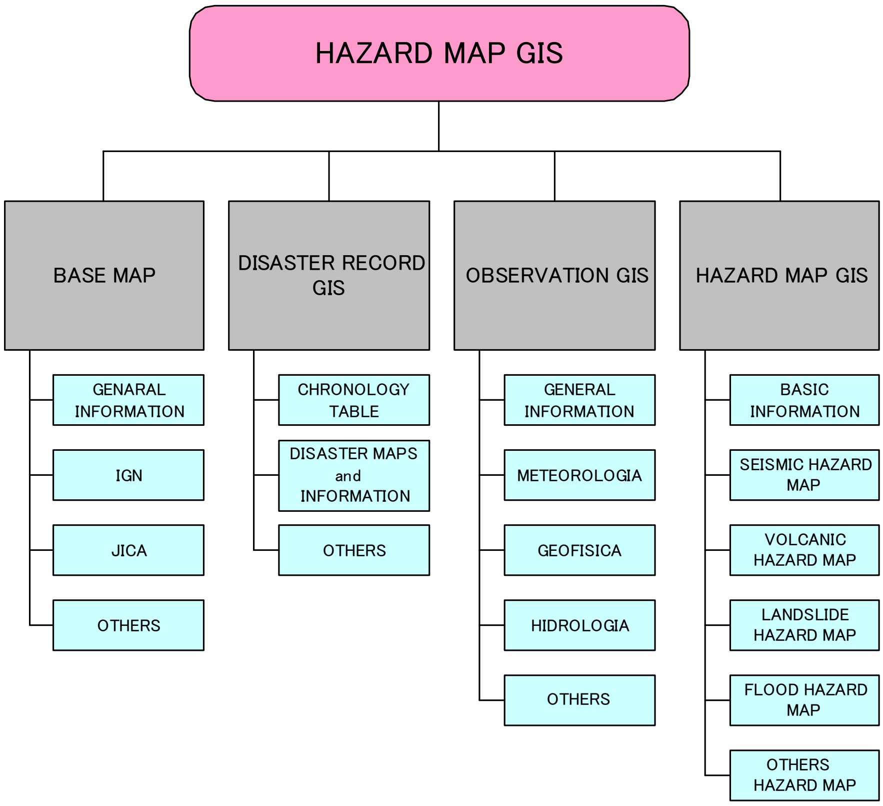

Figure 4.3-18 Outline of hazard map GIS

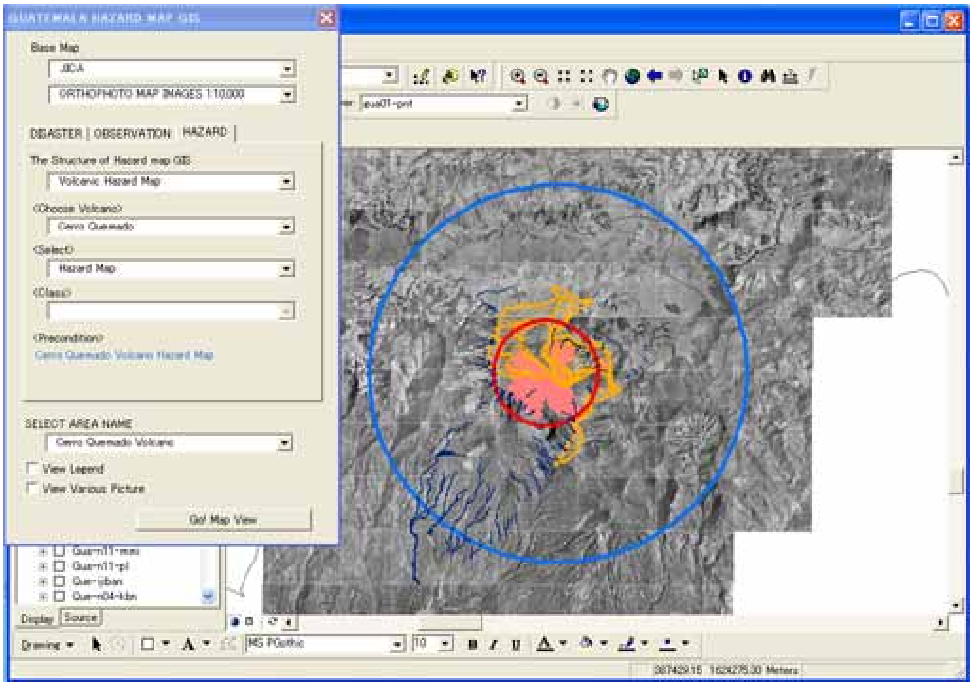

Figure 4.3-19 An example of hazard map GIS screen image